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HORIZONTAL TEMPERATURE VARIABILITY IN THE STRATOSPHERE: GLOBAL VARIATIONS INFERRED FROM CRISTA DATA

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ABSTRACT

In two separate orbital campaigns (November, 1994 and August, 1997), the Cryogenic Infrared Spectrometers and Telescopes for the Atmosphere (CRISTA) instrument acquired global stratospheric data of high accuracy and high spatial resolution. The standard limb-scanned CRISTA measurements resolved atmospheric spatial structures with vertical dimensions $\geq$ 1.5 - 2 km and horizontal dimensions $\geq$ 100 - 200 km.
A fluctuation analysis of horizontal temperature distributions derived from these data is presented. This method is somewhat complementary to conventional power-spectral analysis techniques.

INTRODUCTION

The investigation of horizontal temperature and trace gas fluctuations in the stratosphere is important for two reasons: 1. For validation of satellite experiments one needs to know whether discrepancies in the measured quantities are due to instrumental inaccuracies or atmospheric variability. Hence a statistical description of possible atmospheric variability would be helpful. 2. Quantification of geographical, altitude and time dependencies of such fluctuations allows for the investigation of dynamical processes under certain conditions and on different scales, such as gravity waves (GW), energy or enstrophy cascades. Such processes are often described with the help of power spectral analyses. In practice, such methods put severe demands on datasets. Since high data density and regular spacing are difficult to achieve using satellite data, here another, more robust tool, is presented. Hereby temperature variability is derived from the data without the need to transform them into Fourier space by the use of statistical methods. The properties of this analysis technique are discussed in relation to the two topics mentioned above.

INSTRUMENT AND DATA

CRISTA (Offermann et al., 1999) measured temperatures and trace gases in the middle (4 - 14 μm) and far (15 - 71 μm) infrared by the limb-scanning technique. It was flown on two Space Shuttle missions on a 300 km orbit with 57° inclination during November 3-14, 1994 and August 8-16, 1997. Measurements were taken using four spectrometers and three telescopes simultaneously. In this study, preliminary (Version 1) data of the standard stratospheric mode from the second CRISTA mission (Grossmann, 2000) are used. In this mode the three telescopes covered an altitude regime from about 10 to 55 km with a vertical step width of 2 km. The along-track resolution was nominally about 240 km, the across-track resolution less than 650 km. The latitudinal coverage was ± 74°. Precision and accuracy of stratospheric temperature measurements are about the same as those of the first CRISTA mission (Riese et al., 1999), namely 0.35 K and 1 K, respectively.

METHODS

Three of the four spectrometers were used to derive temperature information from the IR spectral region at 12.63 μm. Thus at every telescope's footprint one temperature measurement was performed. The analysis

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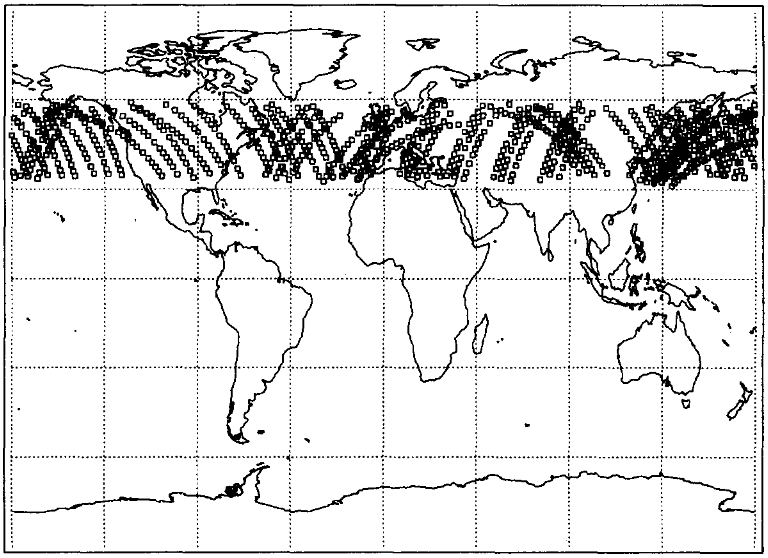

Fig. 1. Bins of the CRISTA dataset at 30 km altitude between 34° N and 56° N on August 12*th*, 1997. Each square represents one measured altitude profile. "Regions" are groups of three parallel satellite tracks each containing nine measurements at the given altitude and latitude band. They were selected for the application of "Method 1".

method presented here is based on the definition of "regions" containing a set of nine measurements for each of the three satellite tracks out of the data within a given latitude band and at a given altitude level as is depicted in Figure 1. Each square in Figure 1 therefore represents an altitude scan (i.e. altitude profile) for August 12*Sth*, 1997. The marked positions represent interpolated values for a nominal altitude of 30 km and within a latitude band from 34° N to 56° N. In Figure 1 it can be seen how altitude profiles form lines, the so-called "satellite tracks". These tracks form groups of three due to the simultaneous use of three different telescopes. From such groups regions are extracted and analyzed. This fluctuation analysis is hereafter referred to as "Method 1". It was performed for latitude bands best suited to the CRISTA horizontal spatial resolution. Ranges of these bands were 75° S - 55° S, 56° S - 34° S, 35° S - 15° S, 15° S - 15° N, 15° N - 35° N, 34° N - 56° N and 55° N - 75° N. Altitude levels were 18, 24, 30, 38, 44 and 50 km. Successive levels are therefore approximately separated from each other by about one scale height. Temperatures of the original measurements were interpolated linearly between two altitude levels to match the above mentioned altitude levels.

Along track analysis was applied in order to exploit the highest possible horizontal resolution of the CRISTA data used in this measurement mode. For each track of one of the previously defined regions, temperature differences of next, second, third and fourth neighbours were calculated. These are defined by their separation distance $i * \delta x \approx i * 240\ km$ with neighbour index i = 1, 2, 3 and 4, respectively. Their separation in time is about $i * \delta t \approx i * 30\ s$, hence the analysis is based on almost instanteneous measurements. For all differences with the same separation within one predefined region, both the mean and the standard deviation σ_i were calculated. Thus σ_i is a measure of the atmospheric variability of temperature fluctuations over the distances covered by this method. The noise level of the method, i.e. the statistical accuracy of σ_i, is given by

$$\sigma_{noise} = \frac{1}{\sqrt{2\,n}}\,\sigma_i, \qquad (1)$$

where n is the number of temperature differences with the same neighbouring index within one region. Latitude bands were chosen to contain nine temperature measurements. Hence without any data gaps this accuracy of next, second, third and fourth neighbours is 14, 15, 17 and 18 % of σ_i, respectively. For zonal averages with typically 10 to 25 regions per day this error is then reduced by a factor of about 3 to 5.

In order to extend the analysis to smaller horizontal scales, two other methods were employed: First, during the whole second CRISTA mission temperature differences of data pairs within distance categories of 0 - 50, 50 - 100, 100 - 150 and 150 - 200 km were calculated at the same altitude levels and within the same latitude bands ("Method 2"). Such pairs were not necessarily located on the same orbit. Miss times are approximatively given by multiples of one orbit period of 90 minutes with a maximum value allowed of 15 hours, or 10 orbit periods. Temperature fluctuations within the same miss distance and miss time category were averaged if this class contained at least 10 data pairs, otherwise they were omitted. Miss distances below 100 km in practice occurred rather seldom and therefore drop out of the statistics (see Figure 4).

Second, radiosonde measurements of temperature during the CRISTA 2 validation campaign (Lehmacher et al., 2000), which lasted for four weeks, were used ("Method 3"). The radiosondes were launched in pairs at Wallops Island (37.9° N, 75.5° W) within miss times of 8 minutes. At 30 km altitude the average of the temperature differences of 10 pairs was taken. The approximate miss distance at this altitude was about 50 to 70 km. The results of these measurements were compared with CRISTA data for the same altitude and within the latitude band 34° N to 56° N.

RESULTS AND DISCUSSION

A global distribution of σ_1 values for Method 1, calculated for 38 km altitude and all latitude bands on August 12*th*, is shown in Figure 2 as coloured squares. Their actual position is the center of each individual region. The main feature discernible from Figure 2 is that temperature variability during this day is much larger in the Southern (Winter) Hemisphere (SH) south of 40° S than at lower latitudes and in almost the whole Northern (Summer) Hemisphere (NH). Interestingly the highest SH variability is found

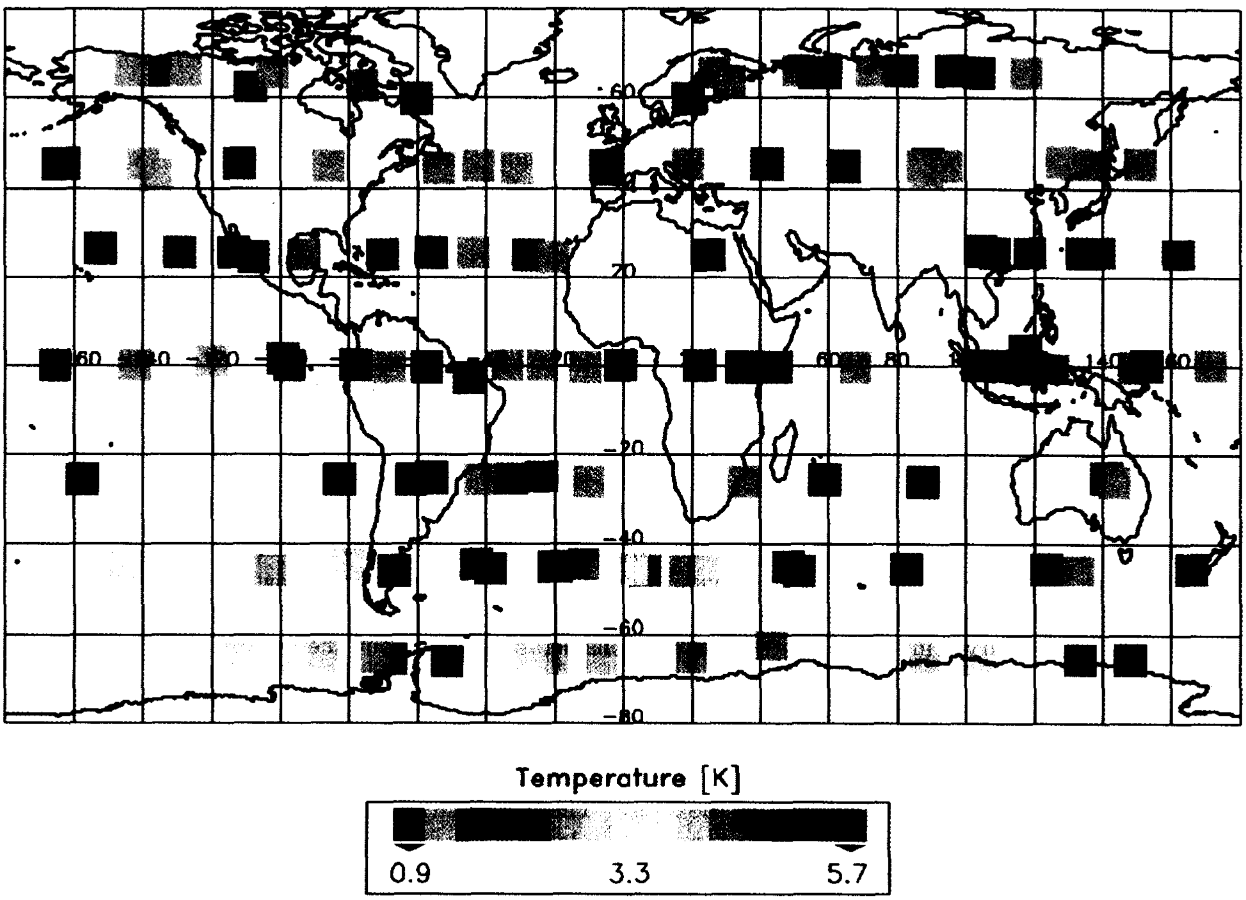

Fig. 2. Global distribution of temperature variability as derived from Method 1 (σ_1 only) for August 12*th*, 1997 at 38 km altitude.

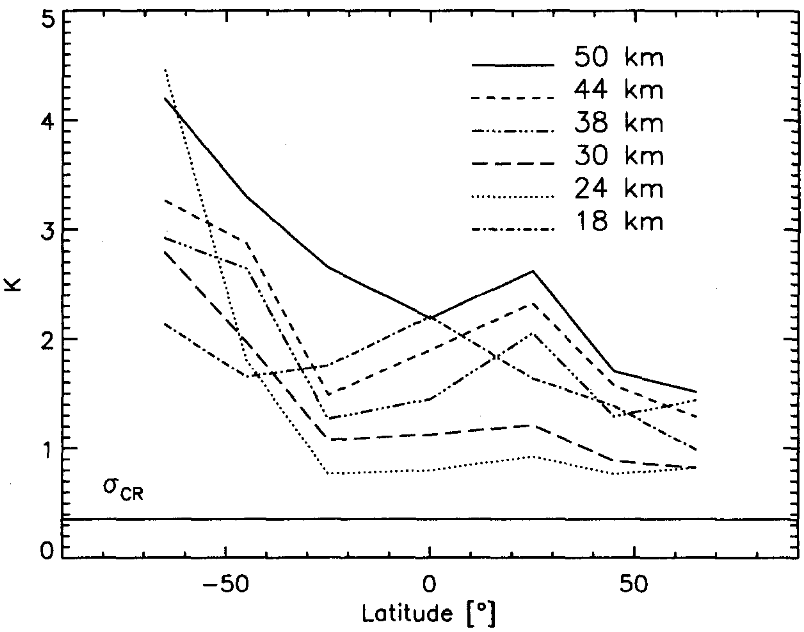

Fig. 3. Zonally averaged temperature variability σ_1 for all altitudes and latitude bands on August 12*th*, 1997 according to Method 1. σ_{CR} is the instrument's noise background.

over the Southern Andes where Eckermann and Preusse (1999) have shown evidence of high mountain lee wave activity during the first CRISTA mission in November 1994. In the Northern Hemisphere, relatively high variability is located over the Western Pacific region and mostly between China and Japan as well as over the Eastern Pacific/Western Atlantic region around Middle America. Both locations have also been found to exhibit high gravity wave (GW) activity at altitudes above 30 km due to strong convective systems (Preusse et al., this issue).

The altitude and latitude dependence of the zonally averaged σ_1 values for Method 1 for the same measurement day is depicted in Figure 3. For the southernmost latitudes below about 30° S, stratospheric temperature variability is likely higher due to the presence of the south polar vortex which has its strongest influence on temperature variability at the 50 km altitude values displayed in Figure 3. North of 30° S temperature variability at 18 km altitude is much higher than at 24 km. For further increasing altitudes it then slowly increases reaching maximum values at 50 km altitude. Hereby the buildup of peak temperature variability at northern midlatitudes between 15 and 35° N is found. Since GW activity at these altitudes is somewhat displaced towards the equator as found from vertical profile analyses (Preusse et al., this issue), this feature may be due to the presence of the subtropical transport barrier which provides strong meridional temperature gradients at these altitudes (not shown). Here strong easterlies with wind speeds on the order of 30 m/s are also found (J. Oberheide, personal communication). All variances shown in Figure 3 are well beyond CRISTA's temperature noise floor σ_{CR} of 0.35 K, which is shown as a horizontal line in this figure. The shapes of the curves in general do not change considerably throughout the other days of the second CRISTA mission (not shown).

In order to further investigate the dependence of temperature variability on horizontal scale, the results of all three methods are depicted together in Figure 4. The asterisks at 240, 480, 720 and 960 km denote zonally averaged temperature variability from the whole mission as given by σ_i, i =1, 2, 3 and 4, respectively, and are called "along-track fluctuations" in the figure. The bars indicate standard deviations obtained by zonally averaging the σ_i values. Black circles labeled "random data pair" represent temperature fluctuations as obtained from Method 2 when integration over the whole mission is performed. Surprisingly, temperature variability as derived from both methods is found to be within the same range from about 0.65 to 1.25 K despite the differing miss distances (miss times are less than a few minutes). Only for the campaign data called "radiosonde pairs, Wallops Island" in Figure 4 does temperature variability drop significantly. Thus

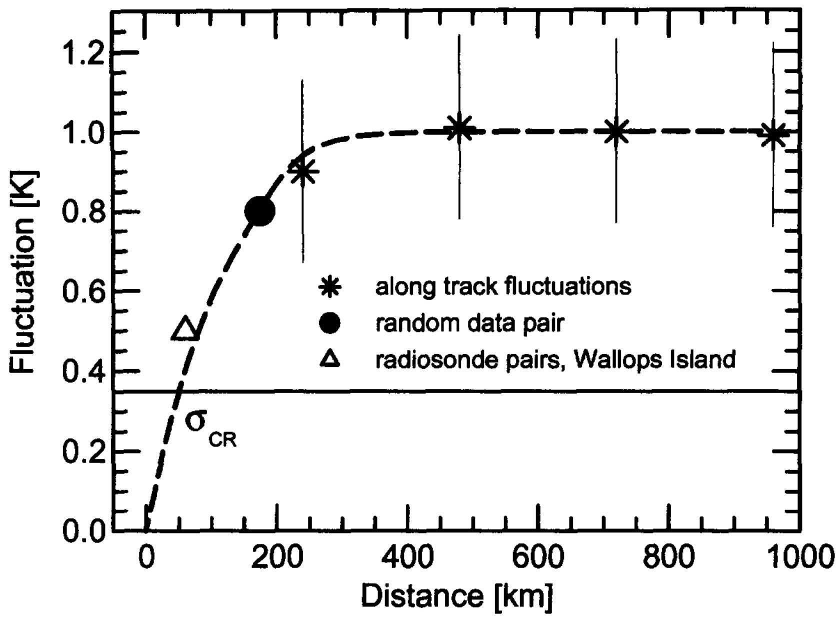

Fig. 4. Temperature fluctuations versus horizontal scale at 30 km between 34° N and 56° N integrated over the whole datasets. Asterisks mark results as obtained from Method 1 called "along-track fluctuations". The black circle marks the result of Method 2 ("random data pair") and the triangle marks the outcome of Method 3 analyses ("radiosonde pairs, Wallops Island"). The dashed line is meant to guide the eye. See text for further explanations.

only at the smallest spatial and temporal scales does this variability vanish. Qualitatively the same picture holds for miss times (not shown). Therefore these data suggest that at all scales beyond about 100 - 200 km a certain "background" of temperature fluctuations exists which must be due to variability at smaller scales. At scales on the order of between a few km and a few tens of km, a potential source could be GWs. Quasi-2-dimensional turbulence could in principle also influence the shape of the curve shown in Figure 4 but is rather implausible to exist at these altitudes following the findings of Koshyk et al. (1999). Enhanced GW activity as is expected for the middle stratosphere compared to the troposphere would not allow for a quasi-2-dimensional turbulence regime.

SUMMARY AND CONCLUSIONS

A new method (Method 1) for the quantification of temperature variability at horizontal scales from 240 to 960 km based on statistical tools has been presented using CRISTA data from the second mission in August 1997. For the measurement period, temporal variability is low, while there is a strong dependence on both altitude and latitude. This variability is most probably not only due to GWs. However, it must partially stem from scales below about 100 - 200 km, a conclusion that is supported by the two other methods presented (Method 2 and 3). A potential source of this variability could thus be an overall background of GW activity at these smallest scales. Mid-stratospheric horizontal power spectra of temperature inferred directly from limb-radiance data from the second CRISTA mission are also indicative of relatively intense small-scale variability (Eidmann et al., this issue).

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